A Summary of the CMIP5 Experiment Design

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1. Preface and overview.

At its recent meeting (September 2008) involving 20 climate modeling groups from around the world (i.e., most of the major groups performing climate change research today), the WCRP's Working Group on Coupled Modelling (WGCM), with input from IGBP's AIMES, agreed on a new set of coordinated climate model experiments, to be known as phase five of the Coupled Model Intercomparison Project (CMIP5). The purpose of these experiments is to address outstanding scientific questions that arose as part of the IPCC AR4 assessment process, improve understanding of climate, and to provide estimates of future climate change that will be useful to those considering its possible consequences. As in past CMIP phases[5], results from this new set of simulations is expected to lead to climate information and knowledge of particular relevance to future international assessments of climate science (e.g., the IPCC's AR5, now scheduled to be published in early 2013). Consequently, for the compelling science motivations and for the interest in the IPCC AR5, the CMIP5 simulations will become a high priority on the research agendas of most major climate modeling centers. *CMIP5 is meant to provide a framework for coordinated climate change experiments for the next five years and thus includes simulations for assessment in the AR5 as well as others that extend beyond the AR5. CMIP5 is not, however, meant to be comprehensive; it cannot possibly include all the different model intercomparison activities that might be of value, and it is expected that various groups and interested parties will develop additional experiments that might build on and augment the experiments described here.* In the IPCC assessment context, it is expected that CMIP5 will provide information of value to all three IPCC Working Groups.

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[1] There are many individuals who have contributed in substantive ways to this document. Pierre Friedlingstein, Olivier Boucher, Mark Webb, Jonathan Gregory, and Myles Allen have made particularly important suggestions and comments that have substantially altered and improved the design of the suite of long-term experiments. Additional helpful suggestions have been provided by: Sandrine Bony, Pascale Braconnot, Peter Cox, Veronika Eyring, Greg Flato, Nathan Gillett, Marco Giorgetta, Bala Govindasamy, Wilco Hazeleger, Gabi Hegerl, Chris Jones, Gareth Jones, Masihide Kimoto, Ben Kirtman, Corinne LeQuéré, David Lobell, Jason Lowe, Mike MacCracken, John Mitchell, James Murphy, Tim Palmer, Ben Santer, Cath Senior, Detlef Stammer, Bjorn Stevens, Tim Stockdale, Dáithí Stone, Peter Stott, and Keith Williams. Many others have contributed to the discussions that have led to the present experiment design. Apologies to those we have forgotten to include here.

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[4] National Center for Atmospheric Research (NCAR) and Co-Chair of the WCRP's Working Group on Coupled Modelling (WGCM).

[5] Phase 3 of CMIP (ca. 2004-2006) provided projections of climate change informing the IPCC's AR4. Additional simulations were collected more recently during phase 4 (Meehl et al., 2007), which provide information concerning the separate anthropogenic and natural influences on climate.

2. Introduction.

CMIP5 promotes a standard set of model simulations in order to:

- evaluate how realistic the models are in simulating the recent past,
- provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond), and
- understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle

This set of aims has influenced the prioritization of the CMIP5 experiments.

A summary of the CMIP5 experiments is provided here, and the purposes of each simulation are enumerated. This integrated set of simulations addresses the priorities of several different communities and incorporates some of the ideas and suggestions from a number of workshops, meetings, and individuals, including the:

- Aspen Global Change Institute Workshop (July 2006)
- joint WGCM/AIMES meeting (Victoria, September 2006)
- Snowmass Energy Modeling Forum (July 2007)
- IPCC Expert Meeting on New Scenarios (Noordwijkerhout, September 2007)
- International Detection and Attribution Group (IDAG) meeting (Boulder, January 2008)
- WGCM meetings (Hamburg, September 2007; Paris, September 2008)
- WGNE meeting (Montreal, November 2008)
- the WGCM members and representatives from the individual modeling groups
- individuals who have commented on earlier versions of this document.

As noted above, under the CMIP5 strategy[6] there are two distinct foci of the model experiments: 1) near-term decadal prediction simulations (10- to 30-years) initialized in some way with observed ocean state and sea-ice, and 2) long-term (century time-scale) simulations initialized from the end of freely evolving atmospheric/ocean GCM simulations of the historical period. CMIP5 also recognizes that some groups may wish to perform simulations with unusually high resolution atmospheric models or models with more complete treatments of atmospheric chemistry. When computer resources are insufficient to allow a fully coupled simulation, the option is provided to perform so-called “time-slice” experiments of both the present-day (AMIP period) and the future (specifically, the decade 2026-2035). In time-slice simulations of the future, projected changes in sea surface temperature (SST) and sea-ice obtained from a fully coupled atmosphere/ocean GCM’s simulation will be imposed.

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[6] Hibbard, K. A., G. A. Meehl, P. Cox, and P. Friedlingstein (2007): A strategy for climate change stabilization experiments. *EOS*, **88**, 217, 219, 221. Also, Meehl, G.A., and K.A. Hibbard, 2007: A strategy for climate change stabilization experiments with AOGCMs and ESMs. WCRP Informal Report No. 3/2007, ICPO Publication No. 112, IGBP Report No. 57, World Climate Research Programme: Geneva, 35 pp.

Individual groups may choose to perform either the near-term or the long-term experiments, or they may be able to do both. With certain models it may only be possible to perform the time-slice experiments.

We first provide a general overview of the CMIP5 experimental framework with schematic diagrams and two summary tables. Then in subsequent sections we provide a more detailed description of each experiment with the support of additional tables.

Due to the large numbers of simulations included in the CMIP5 framework, the experiments for both timescales are grouped into a "core" set, and then one or two "tiers" (Fig. 1). To allow for a systematic model intercomparison and to produce a credible multi-model dataset for analysis, the core experiments should be completed by all groups. The tier 1 experiments examine specific aspects of climate model forcing, response, and processes, and tier 2 experiments go deeper into those aspects. Thus one could think of the sequence, proceeding from core to tier 1 to tier 2, as a progression from basic to more detailed simulations to explore multiple aspects of climate system response and projections. There are fewer experiments in the decadal prediction set which accounts for the absence of a second tier. For each focus, it is recommended that groups address the core experiments first, followed by the tier 1 and tier 2 experiments, depending on interests and available resources.

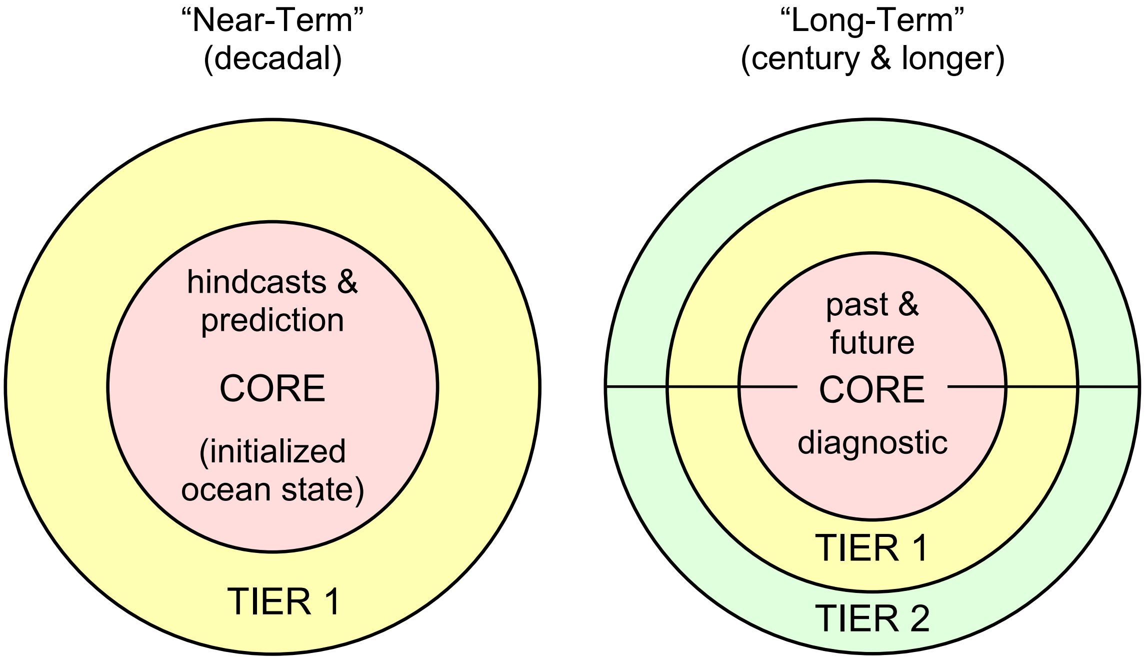


Figure 1: Schematic of the two focus areas of CMIP5, with each one divided into prioritized tiers of experiments. The colors used in this figure are also used to indicate the relative priorities of the experiments summarized in the tables that appear later in this document.

To fill in the experiments outlined conceptually in Fig. 1, Figs. 2 and 3 show abbreviated summaries of the CMIP5 model experiments in schematic form. The decadal prediction experiments are shown in Fig. 2.

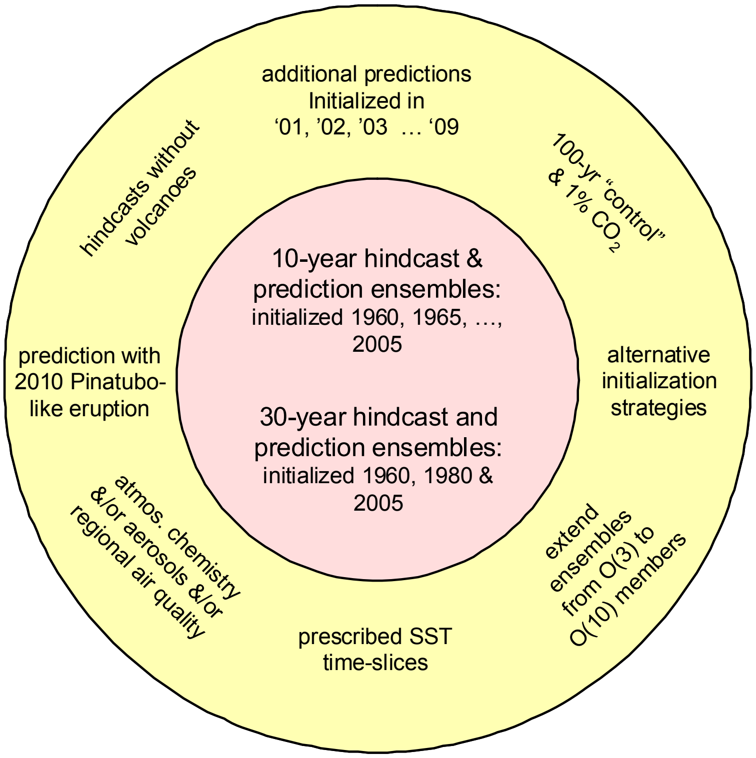
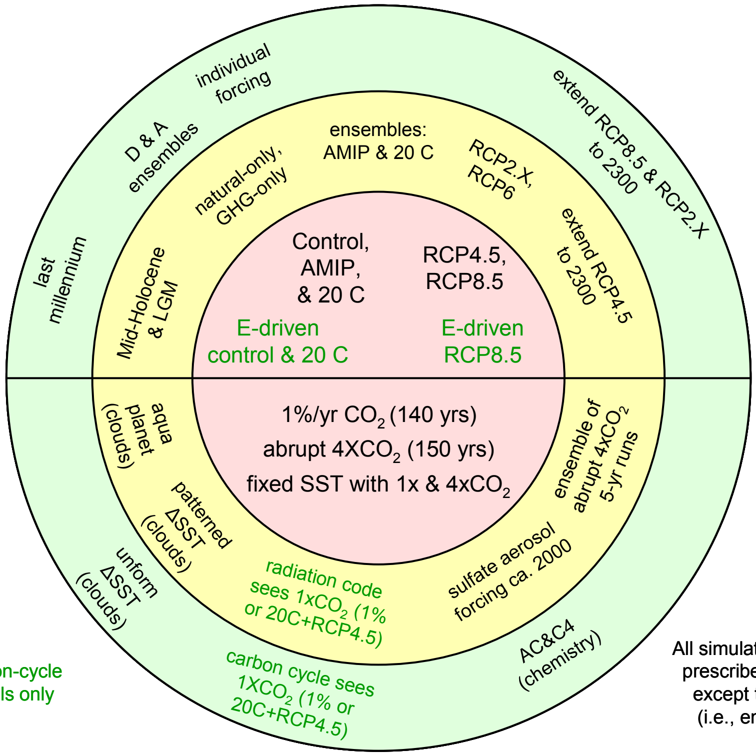


Figure 2. Schematic summary of CMIP5 decadal prediction experiments.

Details will be given below regarding these experiments, but by way of introduction we note that there are two core experiments, one a set of 10 year hindcasts or predictions initialized from climate states in the years 1960, 1965, 1970, and every five years to 2005, with this last simulation representing the sole actual prediction beyond the present (i.e., beyond 2009). In these 10-year simulations, it will be possible to assess model skill in forecasting climate change on time-scales when the initial climate state may exert some influence. The other core experiment extends the 10-year simulations initialized in 1960, 1980, and 2005 by an additional 20 years. It is at this somewhat longer timescale that the external forcing from increasing GHGs should become more important. It is desired that at least three ensemble members be performed for each of the core experiments, with extension to at least 10 members as a tier 1 experiment.

The tier 1 near-term experiments also include predictions with 1) additional initial states in the 2000's when ocean data in particular is of better quality, 2) volcanic eruptions removed from the hindcasts, 3) a hypothetical volcanic eruption imposed in one of the predictions of future climate, 4) different initialization methodologies, and 5) the option of performing high resolution time slice experiments with specified SSTs for certain decades in the future with a particular focus on 2026-2035. These time-slice experiments would also be appropriate for models that include computationally expensive atmospheric chemistry treatments. For models not used to do the long-term experiments, a relatively short "control" run and and 1% per year CO_2 increase experiment is called for, and there is also the possibility of an atmospheric chemistry/pollutant experiment.

Turning to the CMIP5 long-term experiments, Fig. 3 shows the set of core experiments that include AMIP runs, a coupled control run and at least one 20th century experiment with all forcings (also referred to here as an "historical" run). There are two projection simulations forced with specified concentrations consistent with a high emissions scenario (RCP8.5) and a medium mitigation scenario (RCP4.5). For Earth System Models that include a coupled carbon cycle, there are control, 20th century simulations, and a future simulation with the high scenario (RCP8.5) driven by emissions.



Coupled carbon-cycle climate models only

All simulations are forced by prescribed concentrations except those "E-driven" (i.e., emission-driven).

Figure 3: Schematic summary of CMIP5 long-term experiments.

For the diagnostic core experiments (in the lower hemisphere), there are the calibration-type runs with 1% per year CO_2 increase to diagnose transient climate response (TCR), an abrupt $4XCO_2$ increase experiment to diagnose equilibrium climate sensitivity and to estimate both the forcing and some of the important feedbacks, and there are fixed SST experiments to refine the estimates of forcing and help interpret differences in model response.

The tier 1 and tier 2 experiments explore various aspects of the core experiments in further detail. For earth system models, there are two carbon cycle feedback experiments. In the first, climate change is suppressed (by not letting the radiation code "see" the increasing CO_2 concentration), so the carbon cycle responds only to the changing CO_2. In the second, the climate responds to CO_2 increases, but the CO_2 increase is hidden from the carbon cycle.. The surface fluxes of CO_2 will be saved in these experiments and compared with those from the corresponding "core" experiment in which the carbon cycle simultaneously responds to both climate and CO_2 concentration changes. From these fluxes, the strength of carbon climate feedback can be expressed in terms of the difference in allowable emissions. There is a suite of cloud feedback experiments, some paleoclimate experiments to study the response of the models under much different forcing, experiments for climate change detection/attribution studies with only natural forcing or only GHG forcing (as well as some single forcing experiments), 21st century runs with the other two RCPs (RCP2.x and RCP6), and extending the RCP future simulations out to year 2300. There are diagnostic experiments for additional feedback analyses with short $4XCO_2$ experiments, an experiment to quantify the magnitude of the aerosol forcing, and a coordinated chemistry experiment called "AC&C4".

Several of the experiments require specification of concentrations or emissions of various atmospheric constituents (e.g., greenhouse gases and aerosols). The Integrated Assessment Model Consortium will provide the Atmospheric Chemistry and Climate (AC&C) community the concentrations, emissions and time-evolving land use changes to be used in the simulations. Then AC&C will convert these data to global grids for direct use in the AOGCMs and ESMs according to the following tentative schedule: 1) pre-industrial values by the end of December, 2008, 2) historical values through 2005 by the end of March, 2009, and 3) for future scenarios (which are initiated in 2006) by the end of June, 2009. PCMDI will make these available to the modeling groups as soon as they have been received.

The near-term and long-term experiments are summarized in abbreviated form in Tables A and B below, with approximate estimates of the number of simulated years required in each case. Further itemized details of the experiments will be provided in subsequent sections below.

It is of some interest to note that for CMIP3 (the climate model experiments that contributed to the IPCC's Fourth Assessment Report), each modeling group submitted on average 1750 years of model output from the first member of what was often a multi-member ensemble of runs. Totaling the years across each model's ensemble, we find on average nearly 2800 years per model, but the total varied substantially from one model to another (500 to 8400 years with a median of 2200 years). Thus, the long-term and near-term CMIP5 "core" experiment suite, calling for at minimum ~2300 years, is comparable to that obtained from modeling groups in CMIP3, at least in terms of simulated years.

Table A: Summary of decadal prediction experiments and estimates of years of simulation. The first digit of each experiment number indicates in which subsequent table the experiment appears.

	#	**Experiment**	**Core**	**Tier 1**
Initialized with Observed Ocean State	1.1	Ensembles of 10-year hindcasts and predictions	3x10x10	
	1.2	Ensembles of 30-year hindcasts and predictions	3x3x20	
	1.1-E, 1.2-E	Increase ensemble sizes of 1.1 and 1.2		~7x10x10, ~7x3x20
	1.1-I	Initialize 10-year simulations from additional start dates annually in 2000s		≥3x(≥5)x10
	3.3	AMIP(1979-2008)		30
	3.1-S	100-yr control		100
	6.1-S	1%/yr CO_2 increase		80
	1.3	Hindcasts without volcanoes		≥3x5x(≥10)
	1.4	Predictions with 2010 Pinatubo-like eruption		≥3x(≥10)
	1.5	Initialize with alternative strategies		≥3x(≥10)
	1.6	Run with more complete atmos. chemistry		≥1x(≥10)
		SUBTOTALS:	**480**	**≥1700**
“Time Slice”	3.3	AMIP (1979-2008)		30
	2.1	Future “time-slice” experiment (2026-2035)		10
	3.3-E	AMIP ensemble		≥2x30
	2.1-E	Future “time-slice” experiment ensemble		≥2x10
	6.5-6.8	Cloud diagnostic experiments		≥105
		SUBTOTALS:		**≥225**

Table B: Summary of long-term experiments and estimates of years of simulation. The first digit of each experiment number indicates in which subsequent table the experiment appears.

	#	Experiment	Core	Tier 1	Tier 2
ALL MODELS	3.1	Coupled model, pre-industrial control	≥500		
	3.2 & 3.2-E	historical (1850-2005) ensemble	156	(≥2)x156	
	3.3 & 3.3-E	AMIP ensemble (1979-2008)	30	(≥2)x30	
	3.4	Mid-Holocene (6 kyr ago)		≥100	
	3.5	Last Glacial Maximum (21 kyr ago)		≥100	
	3.6	Last Millennium (850-1850)			1000
	4.1, 4.2, 4.3, & 4.4	Projected responses to concentrations based on RCP's 4.5 & 8.5 (core) and RCP's 2.X & 6 (tier 1)	2x95	2x95	
	4.1-L	Extension of RCP4.5 through year 2300		200	
	4.2-L & 4.3-L	Extension of RCP8.5 and RCP2.X through year 2300			400
	6.1	Idealized 1%/yr simulations	140		
	6.2 a&b	Prescribed SST expts. to diagnose "fast" responses to 4xCO_2	2x(≥30)		
	6.3	Diagnosis of climate system "slow" responses to abrupt quadrupling of CO_2	150		
	6.3-E	Ensemble of 5-year simulations to diagnose "fast" responses to abrupt 4xCO_2 increase.		11x5	
	6.4	Prescribed SST expts. to diagnose "fast" responses to sulfate aerosols (ca. 2000)		≥30	
	6.5, 6.6 & 6.8	Prescribed change in CO_2 concentration (tier1), and "patterned" (tier1) and uniform (tier 2) changes in SST for diagnosing cloud responses.		2x30	30
	6.7a&b&c	Aqua-planet cloud responses (control, 4xCO_2 and +4K experiments)		3x5	
	7.1 & 7.2	historical runs with only natural forcing and only GHG forcing		2x156	
	7.3	historical runs forced by individual agents			(≥1)x156
	(7.1-7.3)-E	Additional ensemble members of 7.1-7.3			(≥1)x(≥2)x 156
		SUBTOTALS:	**≥1226**	**≥1592**	**≥1898**
ESM'S	5.1	Pre-industrial control with CO_2 concentration determined by model	≥251		
	5.2 & 5.3	Emission-driven historical and RCP8.5 simulations.	251		
	5.4 & 5.5	Diagnosis of carbon climate feedback components in prescribed CO_2 experiments (following "idealized" or more "realistic" pathways) in which CO_2 surface fluxes are saved and allowable emissions computed.		140 or 251*	140 or 251*
		TOTALS:	**≥1718**	**≥1727**	**≥2038**

In the following sections, the CMIP5 experiments are grouped into tables according to their primary objectives and the simulations are described in more detail:

Table 1: "Decadal" prediction (hindcasts and projections), initialized with observed ocean state
Table 2: Near-term "time-slice" experiments to accommodate computationally demanding models.
Table 3: Baseline long-term simulations for model evaluation and for understanding historical and paleo climates
Table 4: Long-term climate projections.
Table 5: For coupled carbon/climate models (Earth System Models or ESMs), additional simulations of the past and future.
Table 6: Diagnostic experiments for understanding the long-term simulations.
Table 7: Long-term simulations for detection and attribution of climate change.

3. Focus on the near term.

a. Decadal prediction (hindcasts and projections).

There is considerable interest in exploring the degree to which future climate states depend on the initial climate state, focusing in particular on whether we can more accurately predict the actual trajectory of future climate (including both forced and unforced change) if we initialize the models with at least the observed ocean state (and perhaps also sea ice and land surface). A broad set of coupled model experiments to explore the decadal prediction problem has been described in the document[7] prepared by the WGCM/WGSIP/CLIVAR/ WCRP sub-group led by Tim Stockdale, and they are summarized in Table 1. An additional description of the new field of decadal prediction is given by Meehl et al. (2008)[8].

Though some groups will target higher resolution versions of their models to better resolve regional climate and extremes in the decadal prediction experiments, high resolution is not a requirement, and the experiments would also be usefully performed with the same model used for the longer-term runs discussed in section 4 below.

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[7] "Coordinated experimentation to study multi-decadal prediction and near-term climate change", WGCM/WGSIP/CLIVAR/WCRP sub-group (Tim Stockdale, Gabi Hegerl , Jerry Meehl, James Murphy, Ron Stouffer, Marco Giorgetta, Masihide Kimoto, Tim Palmer, Wilco Hazeleger, Detlef Stammer, Ben Kirtman and George Boer), 2008.

[8] Meehl, G. A., L. Goddard, J. Murphy, R. J. Stouffer, G. Boer, G. Danabasoglu, K. Dixon, M. A. Giorgetta, A. Greene, E. Hawkins, G. Hegerl, D. Karoly, N. Keenlyside, M. Kimoto, B. Kirtman, A. Navarra, R. Pulwarty, D. Smith, D. Stammer, and T. Stockdale (2008): Decadal prediction: Can it be skillful? , *Bull. Amer. Meteorol. Soc.,* submitted.

Table 1. Summary of decadal prediction experiments.

	#	Experiment	Notes	# of years
CORE	1.1	Ensembles of 10-year hindcasts and predictions	With ocean initial conditions in some way representative of the observed anomalies or full fields for the start date, simulations should be initialized towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 and 2005. A minimum ensemble size of 3 should be produced for each start date. The atmospheric composition (and other conditions) should be prescribed as in the historical run (expt. 3.2) and the RCP4.5 scenario (expt. 4.1) of the long-term suite of experiments.	3x10x10
	1.2	Ensembles of 30-year hindcasts and predictions	Extend to 30 years the expt. 1.1 integrations with initial dates near the end of 1960, 1980 and 2005. A minimum ensemble size of 3 should be produced for each start date.	3x3x20
TIER 1	1.1-E, 1.2-E	Increase ensemble size	Additional runs to expand each ensemble to a size of O(10).	~7x10x10, ~7x3x20
	1.1-I	Initialize 10-year simulations from additional start dates	As in 1.1 and 1.1-E, but initialized near the end of 2001, 2002, 2003, 2004, 2006 (2007, and beyond) to take advantage of the better ocean data of the Argo float era	≥3x(≥5)x10
	3.3	AMIP (1979-2008)	This run is described in Table 3 (expt. 3.3).	30
	3.1-S	A shortened pre-industrial control	This is a shortened version of the pre-industrial control run described in Table 3 (expt. 3.1).	100
	6.1-S	1%/yr CO_2 increase	An- 80 year run with a 1% per year increase in CO_2 (a shortened version of expt. 6.1) , initialized at year 20 of the control run (3.1-S)..	80
	1.3	Hindcasts without volcanoes	Additional runs initialized near end of 1960, 1975, 1980, 1985 and 1990 as in expts. 1.1 and 1.2, but without the Agung, El Chichon and Pinatubo eruptions.	≥3x5x(≥10)
	1.4	Predictions with 2010 Pinatubo-like eruption	An additional run initialized near end of 2005 as in expt. 1.1, but with a Pinatubo-like eruption imposed in 2010.	≥3x(≥10)
	1.5	Initialize with alternative strategies	Since there is at present no generally accepted "best" way to initialize models, some groups may choose to try different initialization methods.	≥3x(≥10)
	1.6	Run with more complete atmos. chemistry	The chemistry/aerosol community plans to put together experiments with short-lived species and pollutants (probably two to three years hence).	≥1x(≥10)

b. “Time-slice” experiments with computationally demanding models.

The highest resolution and most comprehensive climate models require enormous computing resources, which will likely make it impossible to use them to complete the many multi-century simulations called for under the suite of CMIP5 experiments. An alternative is to perform “time-slice” experiments with atmosphere-only models forced by prescribed SSTs and sea ice (as in AMIP experiments). The surface boundary forcing (e.g., SSTs) must be obtained from future scenario runs performed with coupled atmosphere ocean models that are less computationally demanding. “Time-slice” experiments offer opportunities to (for example) to:

- explore the implications of running climate models at high resolution,
- examine the regional effects of climate change at small scales where impacts are felt,
- study the air quality implications of climate change with models that include sophisticated treatments of atmospheric chemistry, and
- obtain more robust statistics characterizing changes in climate, in particular the likelihood of rare or extreme events.

The time-slice experiments are listed in the Table 2 below. *All years or ranges of years appearing here or elsewhere in this document should be interpreted as including all months from the beginning of the first year through the end of the last year* (e.g., 1979-2008 is a simulation initiated on 1 January 1979 and ending on 31 December 2008).

Table 2. “Time-slice” experiments for 1979-2008 and 2026-2035.

	#	Experiment	Notes	# of years
TIER 1	3.3	AMIP (1979-2008)	This run is described in Table 3 (expt. 3.3), but is listed here with the understanding that models doing time-slice experiments with computationally demanding models would not likely be able to complete the core suite of long-term experiments.	30
	2.1	Future “time-slice” experiment (2026-2035)	Simulation of a future decade covering the years 2026-2035, with prescribed SSTs and sea ice concentration anomalies (relative to expt. 3.3) based on one of the following pairs of coupled atmosphere/ocean climate model runs: 1. the difference in climatology between years 2026-2035 of RCP4.5 (expt. 4.1) and years 1979-2008 of the historical run (expt. 3.2), or 2. the difference in climatology between years 2026-2035 of the RCP4.5 30-year run initialized from observations in the year 2005 (expt. 1.2) and a climatology for years 1979-2008 based on a subset of the years covered in the expt. 1.1 series of 10-year simulations (i.e., 1979-1980, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2008 from the runs initialized near the end of 1975, 1980, …, 2005, respectively)	10
TIER 2	3.3-E	AMIP ensemble	Additional AMIP runs (expt. 3.3, but with different initial conditions imposed on the atmosphere and possibly also the land) yielding an ensemble of size ≥3 (and if practical, much larger).	≥2x30
	2.1-E	Future “time-slice” experiment ensemble	Additional expt. 2.1 runs (but with different initial conditions imposed on the atmosphere, sea-ice, and ocean and possibly also the land) yielding an ensemble of size ≥3 (and if practical, much larger). The changes in climatological SSTs and sea-ice used in prescribing the SST and sea-ice in these extended time-slice runs should, when available, be taken from more than one pair of coupled atmosphere/ocean model runs.	≥2x10
	6.5-6.8	Cloud diagnostic experiments	Prescribed SST experiments, consistent with CFMIP requirements, described fully in Table 6.	≥105

Further notes, and issues that need to be considered include the following:

1) RCP4.5 is chosen as a “central” scenario, though choice of scenario does not make much difference for this timescale since the scenarios do not diverge much

before 2030. For consistency with the long-term prediction experiments (Table 4) RCP4.5 is chosen for the decadal prediction experiments.

2) Care must be taken in specifying changes in SSTs and sea ice for the period 2026-2035. Future *anomalies* obtained from the coupled model runs should be added to the observed present climate to get future SST and sea ice concentration. Special care must be taken to avoid sea ice concentrations dropping below 0% (or rising above 100%).
3) For the purposes of determining the pdf's of the altered future climate state relative to the present (and in particular to determine changes in the frequency of rare events), it would also be useful to perform these large ensembles of time-slice experiments with the atmospheric components of the coupled models used in the longer-term experiments (i.e., as opposed to higher resolution discussed here).
4) Rough estimates of model sensitivity and diagnosis of clouds and cloud feedbacks can be made by performing the additional prescribed SST experiments described in Table 6.

c. Decadal prediction experiment details

Core runs:

1.1 10 year integrations with initial dates towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 and 2005 (see below).
Ensemble size of 3, optionally to be increased to O(10)
Ocean initial conditions should be in some way representative of the observed anomalies or full fields for the start date.
Land, sea-ice and atmosphere initial conditions left to the discretion of each group.

1.2 Extend integrations with initial dates near the end of 1960, 1980 and 2005 to 30 yrs.
Each start date to use a 3 member ensemble, optionally to be increased to O(10)
Ocean initial conditions represent the observed anomalies or full fields.

Further details on the core runs:

- Calendar start date can be 1st September, 1st November, 1st December or 1st January, according to the convenience of the modeling group. Dates should allow complete years/decades to be analyzed, e.g. start 1st Sep 1960, 1st Nov 1960 or 1st Jan 1961.
- Actual integration length should be long enough to produce 10 or 30 complete calendar years. It is likely that any extra 'initial' months would be discarded in the analysis.
- Choice of initial conditions is up to each group, subject to the principle that they should represent in some way the observed state of the climate system for the start date. Analyses of past ocean states and/or anomalies are available. Methods to transfer such analyses into an ocean model's initial condition exist. Most

experience so far is of using observed anomalies on top of the coupled model climate, but initializing with the full state is also possible, and will be used by some groups, though the whole question of initializing the climate system presents one of the biggest scientific challenges of decadal prediction.

- All forcings should be included as observed values for past dates, with prescribed concentrations of well-mixed GHGs. The details should be the same as used in the CMIP5 historical (20th century) runs (see Table 3), with the same flexibility on the treatment of ozone and aerosol and the same specified observational datasets.
- For future dates, the RCP4.5 scenario should be used if possible. Specification of reactive species and aerosols will follow those used in the long-term projection runs (see Table 4).
- Any deviations from the standard specifications should be properly documented.
- If sea-ice needs to be specified instead of being modeled, then "no cheating" applies: values cannot be specified using observations later than the start of the run. Persistence of ice from, for example, the year or decade prior to the start of the run is recommended.
- Note the treatment of volcanic aerosol: observed values should be used for past dates, as per CMIP5, but values to be used after 2005 should be specified based on the assumption of no further volcanic eruptions. The model runs are thus configured to predict what will happen to climate, relative to the observed past, if no major eruptions take place, which is a possible outcome for a thirty year period.

Tier 1 runs.

1.1-I 10 year integrations from near end of 2001, 2002, 2003, 2004, 2006 (2007, ..)
Each start date to use a 3 member ensemble, optionally to be increased to O(10)
Runs from 2007 onwards encouraged where possible
These runs make use of the recent well-observed upper 2000 meters of the ocean for temperature and salinity from the Argo floats, and are a step towards possible real-time prediction.

For those models that are able to produce 20th century climate runs, the CMIP5 20th century / RCP4.5 runs should be increased in number to create an ensemble of the desired size of continuous runs extending to 2035. Details as per CMIP5 long-term integrations. Ensemble size to match those used in 1.1 and 1.2.

These runs form a "control" against which the value of initializing near-term climate and decadal forecasts can be measured.

3.3 An AMIP run is called for to allow evaluation of the atmospheric model when subjected to observed SSTs and sea ice.

3.1-S, 6.1-S For models that do not have 20th century and other standard runs, a 100 year control integration is called for along with a 80 year run with a 1% per year increase in CO2, starting 20 years into the control run. These integrations will allow an evaluation of model drift, transient climate response, and ocean heat uptake, and give some idea of the natural coupled modes of variability in the model.

(For groups that want to use an anomaly initialization method, a transient run with observed forcings might be run from the end of the control. With due consideration to the 'cold-start' problem, this could give a late 20th century model climate which could be compared to the observed ocean climate for the purpose of defining initial condition anomalies to be inserted into the model. However, this is considered part of the initialization method - it is up to each group to choose the most suitable approach, and data from such runs will not be collected.)

1.3 Additional runs from 1960, 1975, 1980, 1985 and 1990 without including the Agung, El Chichon and Pinatubo eruptions will enable an assessment of the impact of volcanic eruptions on decadal predictions. It also enables an estimate of "overall skill" of decadal prediction to be made, complementing a dual analysis of "expected skill conditional on no big volcano" and "possible impact of volcano". These runs could either all be 10 years long, or the 1960 and 1980 runs could be 30 years to assess the longer term impact of the volcanoes.

1.4 Repeat of the 1.1 2005 forecast with an imposed "Pinatubo" eruption in 2010

1.5 Comparison of initialization strategies - for example, a repeat of runs (1.1) using an alternate initialization strategy or alternate initial data.

1.6 Impact of short lived species (chemistry) and air quality (experiment note yet formulated).

4. Focus on the longer term.

a. Baseline simulations for model evaluation and for understanding historical and paleoclimates.

The long-term experiments that are most essential for model evaluation include a control run, an historical (1850-2005) run, and an AMIP simulation, which are all core experiments in Table B above. Additional experiments from the more distant past (PMIP experiments) provide further opportunities for model evaluation under very different conditions from present climate The subset of CMIP5 simulations summarized in Table 3 below should be performed both by coupled atmosphere/ocean models (AOGCMs) without carbon cycles and by coupled carbon/climate models (but with prescribed CO_2 concentrations). *As noted earlier, all years or ranges of years specified in this document should be interpreted as including all months from the beginning of the first year through the end of the last year* (e.g., 1850-2005 is a simulation initiated on 1 January 1850 and ending on 31 December 2005).

Table 3. Baseline simulations for model evaluation and for understanding historical and paleoclimates.

	#	**Experiment**	**Notes**	**# of years**
CORE	3.1	Pre-industrial Control	Impose non-evolving, pre-industrial conditions, which may include: Prescribed atmospheric concentrations of • all well-mixed gases (including CO_2) • some short-lived (reactive) species Prescribed non-evolving emissions or concentrations of • natural aerosols or their precursors • some short-lived (reactive) species. Unperturbed land use.	500 (after spin-up period)
	3.2	Historical (1850-2005)	Impose changing conditions (consistent with observations), which may include: • atmospheric composition (including CO_2), due to both anthropogenic and volcanic influences • solar forcing • emissions or concentrations of short-lived species and natural and anthropogenic aerosols or their precursors. • land use	156
	3.3	AMIP (1979-2008)	Impose SSTs & sea ice (from observations), but with other conditions (including CO_2 concentrations and aerosols) as in expt. 3.2.	30
TIER 1	3.2-E	Historical Ensemble	Additional historical runs (expt. 3.2, but initialized at different points in the control) yielding an ensemble of size ≥3.	≥2x156
	3.3-E	AMIP Ensemble	Additional AMIP runs (expt. 3.3, but initialized with different atmospheric and possibly land-surface conditions) yielding an ensemble of size ≥3.	≥2x30
	3.4	Mid-Holocene (6 kyr ago)	Consistent with PMIP specifications, impose Mid-Holocene conditions, including: • orbital parameters • atmospheric concentrations of well-mixed greenhouse gases	≥100 (after spin-up period)
	3.5	Last Glacial Maximum (21 kyr ago)	Consistent with PMIP requirements, impose Last Glacial Maximum conditions, including: • ice sheets • atmospheric concentrations of well-mixed greenhouse gases	≥100 (after spin-up period)
TIER 2	3.6	Last Millennium (850-1850)	Consistent with PMIP requirements, impose evolving conditions, including: • solar variations • volcanic aerosols	1000 (after spin-up period)

Purposes and key diagnostics:

- 3.1 Pre-industrial control
  - a) Serves as the baseline for analysis of historical and future scenario runs with prescribed concentrations.
  - b) Estimate unforced variability of the model
  - c) Diagnose drift in the unforced system
  - d) Provides initial conditions for some of the other experiments
  - e) Provides SSTs and sea-ice concentration for prescription (as a climatology) in expt. 6.2a.
- 3.2 Historical (mid-1800's - 2005)
  - a) Evaluate model performance against present climate and observed climate change.
  - b) Provides initial conditions for future scenario experiments
  - c) Enables detection and attribution studies – evaluation of human impact on past climate (see expts. 7.1-7.3).
  - d) For models with full representation of the carbon cycle, the surface fluxes of CO_2 will be saved in order to calculate allowable emissions implied by the prescribed changes in atmospheric CO_2 and the uptake/release of CO_2 by the oceans and terrestrial biosphere. The separate effects on these surface fluxes of climate change alone (i.e., the carbon-climate feedback) and CO_2 concentration changes alone can be estimated by comparing the allowable emissions in expts. 3.2 and 4.2 with those found in expts. 5.4 and 5.5 (if option 2 is selected, as described in Table 5).
- 3.3 AMIP (1979-2008)
  - a) Evaluate model performance in uncoupled mode
  - b) Determine whether errors seen in coupled model are also evident when sea surface temperatures and sea ice are prescribed
  - c) For those groups carrying out the time-slice experiments (see Table 2) or CFMIP experiments (see Table 6), serves as the baseline for the SST perturbation experiments.
- 3.2-E Historical ensemble
  - a) Better isolate the externally-forced response from total response (which is of particular importance in so-called detection and attribution studies), and obtain an estimate of the "unforced" variability as a residual.
  - b) Enables assessment of statistical significance of differences between simulated and observed fields and between different simulations
  - c) Better determine evolving climatology and the statistics of rare events.
- 3.3-E AMIP ensemble
  - a) Enable assessment of statistical significance of differences between simulated and observed fields and between different simulations
  - b) Better determine evolving climatology and the statistics of rare events.
- 3.4 Mid-Holocene (6 kyr ago)
  - a) Compare with paleodata the model response to known orbital forcing changes and changes in greenhouse gas concentrations.
- 3.5 Last glacial maximum (18 kyr ago)
  - a) Compare with paleodata the model response to ice-age boundary conditions.

  b) Attempt to provide empirical constraints on global climate sensitivity.

3.6 Last Millennium (850-1850)

  a) Evaluate the ability of models to capture observed variability on multi-decadal and longer time-scales.
  b) Determine what fraction of the variability is attributable to "external" forcing and what fraction reflects purely internal variability.
  c) Provides a longer-term perspective for detection and attribution studies.

Further notes and issues that need to be considered include the following:

1) The length of the pre-industrial control run (after initial spin-up) should be long enough to extend to the end of each perturbation experiment that is spawned from it. In order to accommodate an historical run (~1850-2005) followed by a future scenario run (~2006-2300), we need a control run of at least 450 years.
2) The simulations in Table 3 are referred to as prescribed "concentration" runs since the well-mixed gases like CO_2 will be prescribed, not calculated from emissions. Other gases (e.g., ozone) might also be prescribed, but perhaps as a function of altitude, latitude, longitude, and month of year (i.e., seasonally varying). In some models reactive species might be calculated with simple chemistry models, while in others they might be prescribed. The same is true of aerosol species.
3) Specified land-use changes will be supplied to the modeling groups for 20th and 21st century climates, but the implementation of these datasets and whether or not to include dynamic vegetation is up to the individual modeling groups.
4) Care must be taken in accounting for volcanic eruptions that occurred prior to 1850 and also in the future because this can especially impact sea level changes, which respond on multi-century time-scales. If we completely neglect volcanoes prior and after the historical period, then we shall exaggerate their effect on the historical sea level record because during this period the average forcing will become negative (relative to the pre-industrial control). If we include a background volcanic aerosol forcing in the pre-industrial control run, then the same background aerosol should probably be included in the future runs, otherwise there would be a slight exaggeration in the warming (and in sea level increases) throughout the future runs, which would almost certainly be unrealistic. However, imposing a background volcanic aerosol instantaneously in year 2006 of the "future" runs (see Table 1) would also be unrealistic because there were no major volcanic eruptions in 2006. It is recommended that either volcanic aerosols should be omitted entirely from both the control and future runs, or, alternatively, the same background aerosol should be prescribed in both runs.
5) It is recommended that some representation of the solar cycle be included in the 20th and 21st century simulations, though that is left up to the discretion of the modeling groups.
6) The mid-Holocene and "last millennium experiments (3.4 and 3.6) should be initialized from the pre-industrial control run, but the end of this run can extend beyond the end of the control.
7) In the last glacial maximum experiment (3.5) initialize all components except the ocean from the pre-industrial control; Initialize the ocean from a cold spun-up state provided by PMIP.

8) The ice sheet reconstruction to be used in the last glacial maximum experiment (3.5) will be provided by PMIP and will require changes to the surface elevation, land surface type and land fraction.
9) For groups choosing to specify (rather than calculate) the time-varying and evolving ozone concentrations, the most accurate option is to rely on a three dimensional (latitude, altitude, time) monthly mean ozone time series based on observations wherever available and based on model output for the period pre-1970 and in the future (consistent with the chosen RCP). Two options will be made available for use in CMIP5:
   - Option 1: A merged observationally-based and model-based dataset.
     i. For the well-observed period (1979-2006): An activity under the auspices of SPARC will create a consensus observational stratospheric ozone database. The monthly mean database will be zonal means (5° zones) with global coverage, extending from the tropopause to 70 km at high vertical resolution (~1 km), and spanning the period 1979 to 2006 with no missing values. A fixed monthly mean tropospheric ozone climatology, on the same zonal and vertical grid, and representative of the period 1979 to 2006, will be appended to the transient stratospheric ozone fields to provide a seamless database. While this approach can be expected to provide the most accurate past stratospheric ozone forcing, fixed tropospheric concentrations are of course unrealistic and clearly cannot reproduce time-varying tropospheric ozone radiative forcing.
     ii. For the "historical" period (1850-2006): Regression coefficients will be calculated for halocarbon effects (EESC) and/or linear trend and various known natural forcings (volcanic aerosol, solar, ENSO, QBO). The regression coefficients will be used to extrapolate that data back in time, and form a stratospheric ozone time series backward to cover the entire time period 1850-2006.
     iii. For the future (2007 and beyond): A similar procedure could be used to extrapolate into the future, and would capture changes due to halocarbons which will be an important driver of future ozone behavior. However, coupled chemistry climate model (CCM) simulations[9] indicate that future stratospheric ozone abundance is likely to be significantly affected by climate change, and it is not yet possible to estimate this contribution statistically from observations. Therefore, the SPARC CCMVal activity is proposing to provide a stratospheric dataset for CMIP5 that extends the observational database into the future, based on CCM simulations that include the effects of climate change as well as halocarbon changes.
   - Option 2: An entirely model-based dataset: A model-based vertically resolved, monthly mean, full atmosphere ozone and tropospheric aerosol database from

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[9] Eyring, V., D. W. Waugh, G. E. Bodeker, E. Cordero, H. Akiyoshi, J. Austin, S. R. Beagley, B. Boville, P. Braesicke, C. Brühl, N. Butchart, M. P. Chipperfield, M. Dameris, R. Deckert, M. Deushi, S. M. Frith, R. R. Garcia, A. Gettelman, M. Giorgetta, D. E. Kinnison, E. Mancini, E. Manzini, D. R. Marsh, S. Matthes, T. Nagashima, P. A. Newman, J. E. Nielsen, S. Pawson, G. Pitari, D. A. Plummer, E. Rozanov, M. Schraner, J. F. Scinocca, K. Semeniuk, T. G. Shepherd, K. Shibata, B. Steil, R. Stolarski, W. Tian, and M. Yoshiki (2007): Multimodel projections of stratospheric ozone in the 21st century, *J. Geophys. Res.*, 112, D16303, doi:10.1029/2006JD008332.

1850 to 2150 from CCM simulations for the entire time period, past and future, will be provided by AC&C activity 4. This has the advantage of being a physically consistent model dataset throughout time and space and including responses to all relevant forcings/composition changes such as methane and nitrous oxide trends since the pre-industrial. However, the models that have thus far expressed willingness to provide output to this activity are models that in general emphasize the troposphere, placing therefore less emphasis and computational resources on stratospheric physics and chemistry.

b. Future climate projections.

A collaborative process involving the WGCM, AIMES, and the Integrated Assessment Modeling Consortium has produced four emission scenarios for future climate, one non-mitigated and three taking into account various levels of mitigation. These are called "representative concentration pathways" (RCPs)[10] that will begin in year 2006 and continue through the end of year 2300. The RCPs are labeled according to the approximate target radiative forcing at year ~2100 (e.g., RCP4.5 identifies a concentration pathway that approximately results in a radiative forcing of 4.5 W m^{-2} at year 2100, relative to pre-industrial conditions). There is apparently some interest in considering separately the highly uncertain projected changes in land use, but these are not included in the CMIP5 experiments.

Table 4. Future climate projections with models forced by RCP concentrations.

	#	**Experiment**	**Notes**	**# of years**
CORE	4.1	RCP4.5 (2006-2100)	Radiative forcing stabilizes at ~4.5W m^{-2} after 2100. (if ESM, save CO$_2$ fluxes from the surface to calculate allowable emissions to compare to experiment 5.4)	95
	4.2	RCP8.5 (2006-2100)	Radiative forcing reaches ~8.5 W m^{-2} near ~2100. (if ESM, save CO$_2$ fluxes from the surface to calculate allowable emissions to compare to experiment 5.4)	95
TIER 1	4.3	RCP2.X (2006-2100)	Radiative forcing peaks at ~2.X W m^{-2} near 2100.	95
	4.4	RCP6 (2006-2100)	Radiative forcing stabilizes at ~6 W m^{-2} after ~2100.	95
	4.1-L	RCP4.5 extended through year 2300	Extension of expt. 4.1 through the end of the 23rd century.	200
TIER 2	4.2-L & 4.3-L	Extend RCP8.5 & RCP2.X through year 2300	Extension of expts. 4.2 and 4.3 through the end of the 23rd century.	2x200

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[10] For a description of the RCPs, see Moss et al., 2008, report from the IPCC Expert Meeting Towards New Scenarios, held in Noordwijkerhout, The Netherlands, in September, 2007 (see http://www.mnp.nl/ipcc/, "IPCC New Scenarios")

Purposes and key diagnostics:

4.1-4.4 Prescribed concentration scenarios (through year 2100).

  a) Provide estimates of future anthropogenic climate change across a range of future scenarios.
  b) Prescribed concentrations facilitate direct comparison between models with and without a carbon cycle component.
  c) In coupled carbon climate models, allowable anthropogenic emissions of carbon dioxide can be inferred and the implications of carbon flux uncertainty can be estimated. The separate effects on these fluxes of climate change alone (i.e., the carbon-climate feedback) and CO_2 concentration changes alone can be estimated by comparing the allowable emissions in expts. 3.2 and 4.2 with those found in expts. 5.4 and 5.5 (if option 2 is selected, as described in Table 5).
  d) Tune EMICS and integrated assessment models to reproduce these results and then use the simpler models to consider many more scenarios.

4.1-L Extension of the RCP4.5 scenario to year 2300

  a) Provide an estimate of climate change and its implications (e.g., for sea level changes and carbon cycle changes), as projected further into the future.

4.2-L & 4.3-L Extension of the RCP8.5 and RCP2.X scenarios to year 2300

  a) Explore the longer-term implications of a wider range of future scenarios.

Further notes, and issues that need to be considered include the following:

1) There will be continuity of concentrations/emissions and in land use in transitioning from the historical to the future runs.
2) In these runs that project into the future, individual potential volcanic eruptions should be omitted, but a constant background volcanic aerosol may (or may not) be specified. In any case, care must be taken in treating volcanic aerosols, as discussed in the notes after Table 1.
3) See note 9) following Table 3 for options for specifying time-varying and evolving ozone concentrations.

c. Experiments for ESMs (Earth System Models: coupled carbon/climate models), additional simulations of the past and future.

Although the importance of carbon cycle responses can be inferred from the prescribed concentration experiments described above, there is strong interest in exploring in a more direct way how these responses have affected climate over the last century and how they might affect quasi-realistic scenarios of the future. Thus, fully coupled carbon climate model experiments with prescribed anthropogenic CO_2 *emissions* (rather than the resulting concentrations) are of considerable interest. They can be used to explore the impact of the climate-carbon cycle coupling in, most importantly, quantify carbon cycle feedback on projected climate change.

With coupled carbon/climate models, there is also interest in determining what fraction of the total carbon cycle response is attributable to increasing atmospheric CO_2 concentration and what fraction is attributable to climate change (which is referred to as "carbon climate feedback"). The carbon cycle diagnostic experiments (expts. 5.4 and 5.5 in the table below) provide a way of diagnosing the components of the total carbon cycle responses and the roles they play in carbon cycle feedback. This analysis can be used to analyze carbon cycle responses in conjunction with either of two experiments (or both): 1) the 1%/year CO_2 simulation (expt. 6.1), or 2) the historical and RCP4.5 simulations (expts. 3.2 and 4.1). The importance of carbon climate feedback can be quantified from these simulations in terms of allowable emissions.

The set of experiments listed in Table 5 is based on C^4MIP design[11] and will be a subset of the simulations planned for C^4MIP's next phase. *If a coupled carbon climate model is unable to achieve a reasonable pre-industrial balanced carbon budget state, it may not be sensible to perform these prescribed anthropogenic emissions runs, but for other coupled carbon climate models these experiments constitute the core set.*

These simulations cannot be performed unless a model includes a carbon cycle component. The purposes of the prescribed anthropogenic emissions simulations include those enumerated for the prescribed concentration runs (Tables 3 and 4). Unlike the prescribed concentration simulations, future projections of climate change in these simulations will in these simulations include the modeling uncertainties in transforming emissions into concentrations.

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[11] Friedlingstein, P., P. Cox, R. Betts, L. Bopp, W. vonBloh, V. Brovkin, P. Cadule, S. Doney, M.Eby, . Kato, M. Kawamiya, W. Knorr, K. Lindsay, H.D. Mathews, T. Raddatz, P. Rayner, C. Reick, E. Roeckner, K.G. Schnitzler, R. Schnur, K. Strassmann, A.J. Weaver, C. Yoshikawa, and N. Zeng (2006): Climate-carbon cycle feedback analysis: Results from the C4MIP Model Intercomparison. *J. Climate*, **19**, 3337-3353, doi:10.1175/JCLI3800.1.

Table 5. Additional simulations with *fully coupled carbon/climate models only.* In expts. 5.1-5.3 the concentration of CO_2 is determined by the model, while in expts. 5.4 and 5.5 the evolving atmospheric CO_2 concentration is prescribed.

	#	**Experiment**	**Notes**	**# of years**
CORE	5.1	Pre-industrial control	Imposed conditions identical to expt. 3.1, but with CO_2 concentration determined by the model itself.	250 (after spin-up period)
	5.2	Historical (1850-2005)	As in expt. 3.2, but prescribe anthropogenic CO_2 emissions, rather than concentrations. The land surface will change in these models due to imposed land use change, natural changes in vegetation characteristics (in response to climate change and increasing CO_2), and in some models due to succession of natural ecosystems (i.e., dynamic vegetation).	156
	5.3	RCP8.5 (2006-2100)	Continuation of expt.5.2 into the future as in expt. 4.2, but with prescribed anthropogenic CO_2 emissions, rather than concentrations.	95
TIER 1	5.4	experiment to diagnose strength of carbon/climate feedback	This experiment is forced with prescribed atmospheric CO_2 concentrations. There are two equally acceptable options: 1. spin off from the control (expt. 3.1) at the same point as expt. 6.1 and impose conditions identical to the control except that the carbon cycle "sees" atmospheric CO_2 concentration increase at a rate of 1%/yr (as in expt. 6.1); and/or 2. spin off from the control (expt. 3.1) at the same point as expt. 3.2 and impose conditions identical to the control except that the carbon cycle "sees" increasing atmospheric CO_2 concentrations that are identical to those prescribed in expt. 3.2 (for the historical period) and expt. 4.1 (RCP4.5 for the future). For both options, the radiation code sees the same constant CO_2 concentration as in the 3.1 control run (and also under option 2 all other forcing is also omitted). Thus there is little climate change and the carbon cycle only responds to the CO_2 increase.	140 (for option 1); 251 (for option 2)
TIER 2	5.5	Experiment to further understanding of carbon/climate feedback	This simulation is forced with prescribed atmospheric CO_2 concentration. There are two options, as in expt. 5.4, but this time only the radiation code "sees" the rising atmospheric CO_2 concentration (and under option 2 forcing should include any other factors active in expts. 3.2 and 4.1). Forced in this way, the carbon cycle (which "sees" the 3.1 control atmospheric CO_2 concentration) responds to climate change alone.	140 (for option 1); 251 (for option 2)

d. Diagnostic experiments for understanding the long-term simulations.

A key question is: "why, exactly, do models respond differently when forced similarly?" Interpretation of model differences in response to imposed forcing is easiest in the context of idealized experiments in which increases in atmospheric CO_2 concentration are prescribed and all other forcing (e.g., aerosols) is omitted. In particular these experiments are performed to evaluate the strength of various feedbacks that contribute to differences in response. In addition to the traditional benchmark CMIP experiment in which CO_2 concentration increases by 1% per year to obtain the transient climate response (TCR, the globally averaged surface air temperature change at the time of CO_2 doubling), related complementary experiments will be performed to isolate different components of the response (including "fast" responses, often referred to as "forcing", and "slower" responses, often referred to as "feedbacks", as well as different aspects of carbon cycle responses). Table 6 lists the experiments required for a response analysis of this kind. These prescribed concentration experiments should be done with both coupled carbon/climate models and models without a carbon cycle.

The understanding of why models differ in this set of idealized experiments should provide a partial explanation for their differences in the more realistically "forced" runs (i.e., the historical runs and "future scenarios" in Tables 3-5).

In the Hansen-style[12] experiments (6.2a,b, 6.4, 6.5, 6.7b), the impact of CO_2 on the system is gauged while preventing response of the major slowly responding component (i.e., the ocean). This isolates the "fast" responses such as the direct impact of CO_2 on radiation, stratospheric adjustment, and fast cloud and land surface responses.

The Gregory-style[13] analysis (applied to expt. 6.3) is a regression approach, which provides a good estimate of the equilibrium climate sensitivity and the strength of some of the feedbacks that are tied to global mean temperature change.

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[12] Hansen, J., Mki. Sato, R. Ruedy, L. Nazarenko, A. Lacis, G.A. Schmidt, G. Russell, I. Aleinov, M. Bauer, S. Bauer, N. Bell, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Del Genio, G. Faluvegi, E. Fleming, A. Friend, T. Hall, C. Jackman, M. Kelley, N. Kiang, D. Koch, J. Lean, J. Lerner, K. Lo, S. Menon, R. Miller, P. Minnis, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, D. Shindell, P. Stone, S. Sun, N. Tausnev, D. Thresher, B. Wielicki, T. Wong, M. Yao, and S. Zhang (2005): Efficacy of climate forcings. *J. Geophys. Res.* **110**, D18104, doi:10.1029/2005JD005776.

[13] Gregory, J. M., W. J. Ingram, M. A. Palmer, G. S. Jones, P. A. Stott, R. B. Thorpe, J. A. Lowe, T. C. Johns, and K. D. Williams (2004): A new method for diagnosing radiative forcing and climate sensitivity, *Geophys. Res. Lett.*, **31**, L03205, doi:10.1029/2003GL018747. (See also Gregory, J.M., and M. J. Webb, (2008): Tropospheric adjustment induces a cloud component in CO_2 forcing. *J. of Climate*, **21**, 58-71, doi:10.1175/2007JCLI1834.1.)

Table 6. Diagnostic experiments for understanding the long-term simulations.

	#	Experiment	Notes	# of years
CORE	6.1	Idealized 1%/yr run to 4xCO_2.	This run is initialized from the pre-industrial control (expt. 3.1) and CO_2 concentration is prescribed to increase at 1%/yr. All earth system components (including dynamic vegetation) are free to respond.	140
	6.2a	Baseline for two prescribed SST experiments (6.2b, 6.4).	An AMIP-style experiment, but with conditions consistent with the climatology of the control run (expt. 3.1)	≥30
	6.2b	Perturbed run for Hansen-style diagnosis of "fast" climate system responses to 4xCO_2.	As in expt. 6.2a above, but with atmospheric CO_2 concentration quadrupled.	≥30
	6.3	Gregory-style diagnosis of "slow" climate system responses .	Impose an instantaneous quadrupling of atmospheric CO_2 concentration (relative to pre-industrial) and then hold it fixed.	150
TIER 1	6.3-E	Ensemble of runs to improve the estimate of the "fast" climate response diagnosed with the Gregory method.	Generate an ensemble of runs as in expt. 6.3, but terminated after year 5. Each ensemble member must be initialized in a different month of the year. [The initial segment of expt. 6.3 will serve as the 12th member of this ensemble.]	11x5
	6.4	Hansen-style diagnosis of "fast" climate system responses to sulfate aerosols (ca. 2000)	As in expt. 6.2a above, but with aerosols consistent with conditions in year 2000 of the historical run (expt. 3.2)	≥30
	6.5	Cloud response to an imposed 4xCO_2 (Hansen-style diagnosis of "fast" climate system responses).	Identical to expt. 6.2b, but with AMIP SSTs prescribed as in expt. 3.3 (which is the control for this run).	30
	6.6	Cloud response to an imposed change in SST pattern.	Consistent with CFMIP requirements, add a patterned SST perturbation to the AMIP SSTs of expt. 3.3 (which is the "control" for this run).	30
	6.7a	Aqua-planet : control run	Consistent with CFMIP requirements, impose zonally uniform SSTs on a planet without continents.	5
	6.7b	Aqua-planet : cloud response to an imposed 4xCO_2 (Hansen-style diagnosis).	Consistent with CFMIP requirements, impose a 4xCO_2 on zonally uniform SSTs of expt. 6.7a (which is the control for this run).	5
	6.7c	Aqua-planet : cloud response to an imposed uniform change in SST.	Consistent with CFMIP requirements, add a uniform +4K to the zonally uniform SSTs of expt. 6.7a (which is the control for this run).	5
TIER 2	6.8	Cloud response to an imposed uniform change in SST	Consistent with CFMIP requirements, add a uniform +4 K SST to the AMIP SSTs of expt. 3.3 (which is the "control" for this run).	30

Purposes and key diagnostics:

- 6.1 Idealized 1%/yr run
  - a) Measure transient climate sensitivity.
  - b) Evaluate model response under idealized forcing (without the complications of aerosols, land-use changes, etc.)
  - c) Evaluate total carbon-cycle response.
  - d) Compare to previous CMIP model results (e.g., CMIP3 results).
  - e) For models with full representation of the carbon cycle, the surface fluxes of CO_2 will be saved in order to calculate allowable emissions implied by the prescribed changes in atmospheric CO_2 and the uptake/release of CO_2 by the oceans and terrestrial biosphere. The separate effects on these surface fluxes of climate change alone (i.e., the carbon cycle feedback) and CO_2 concentration changes alone can be estimated by comparing the allowable emissions in expt. 6.1 with those found in expt. 5.4 and 5.5 (if option 1 is selected, as described in Table 5).
- 6.2a Baseline for prescribed SST experiments that will estimate the CO_2 and sulfate aerosol radiative forcings (expts. 6.2b and 6.4)
- 6.2b Hansen-style diagnostic.
  - a) Determine the "fast" radiative responses to imposed changes in CO_2. The impact on TOA radiation provides an estimate of CO_2 "radiative forcing" + stratospheric adjustment and "fast" responses of the troposphere/land surface region.
  - b) Determine the "fast" carbon cycle responses to imposed changes in CO_2. The surface carbon flux responses can provide, for example, information concerning CO_2 "fertilization" of vegetation.
- 6.3 Abrupt quadrupling of CO_2.
  - a) Evaluate the equilibrium climate sensitivity of the model following the Gregory regression approach. This is the only expt. that will allow us to determining climate sensitivity.
  - b) Diagnose the strength of various feedbacks.
  - c) Alternate estimate the "fast" radiative response (but this estimate will be noisier than in 6.2b.
- 6.3-E Additional simulations with abrupt quadrupling of CO_2
  - a) Obtain a refined estimate of the "fast" radiative responses using the Gregory method.
  - b) Evaluate "fast" changes in carbon exchange between ocean and atmosphere. This component of carbon cycle response cannot be easily obtained from expts. 6.2a,b, thus this experiment is particularly important for coupled carbon climate models.
- 6.4 Hansen-style diagnostic to determine sulfate aerosol forcing.
- 6.5 CFMIP experiment to diagnose the fast cloud adjustement to CO_2 radiative forcing, which is known to explain part of inter-model differences in cloud response. For carbon climate models, it is recommended that radiation only sees the CO_2 increase, to isolate the cloud adjustments to CO_2 from those

caused by changes in evapotranspiration (due to the possible stomatal response to CO_2 increase).

6.6 CFMIP experiment to examine cloud feedbacks and responses to a prescribed change in SSTs, and isolate the role of atmospheric processes in the response of clouds and precipitation to global warming. The pattern of SST change will be derived from a composite of the CMIP3 OAGCM response at time of CO_2 quadrupling. It will be provided by CFMIP.

6.7 CFMIP aqua-planet experiment to examine model differences and responses under simplified conditions. The 'control' experiment (expt. 6.7a) will use a zonally-uniform distribution of SST, no sea-ice at high latitudes, and perpetual equinoctial conditions (the design of this expt will be close to that proposed by Neale and Hoskins 2001). Expt. 6.7b would be similar to expt. 6.7a except that a $4xCO_2$ would be imposed to examine the fast adjustment of clouds and precipitation to CO_2 radiative forcing. Expt. 6.7c would be similar to expt. 6.7a except that a uniform +4K SST perturbation would be imposed to examine the response of clouds and precipitation to global warming.

6.8 CFMIP experiment to diagnose the cloud feedbacks and responses to a prescribed uniform +4 K change in SST.

Further notes, and issues that need to be considered include the following:

1) These idealized runs will be initiated from the pre-industrial control run (expt. 3.1), and except as noted in Table 6 the same time invariant concentration/emissions/forcing should be imposed as in the control run.
2) In expts. 6.2a,b and 6.4, the SST and sea ice values should come from a climatology of the pre-industrial control run (expt. 3.1). Daily values may be simply linearly interpolated between the monthly mean climatological values; it is not required that the climatological monthly means be recovered exactly from the daily time-series.
3) In all the prescribed SST experiments, land cover would be prescribed. That is, although vegetation could respond (e.g., the leaf area index), vegetation maps would be fixed consistent with the climatology of the pre-industrial control (as would, of course, land-use).
4) The Gregory-style experiments (6.3) are performed instead of the traditional CMIP atmosphere-mixed layer ocean (or slab) model experiments. This is because some groups no longer routinely develop this kind of model in the course of developing new versions of their AOGCMs and ESMs. However, if groups have the capability of running a slab coupled to the atmosphere to compute the equilibrium climate sensitivity, they are encouraged to do so, particularly if they can also perform experiments 6.3 to compare to the slab result.
5) As in all other experiments, models that include a carbon cycle should in prescribed SST experiments (i.e., 3.3, 6.2a,b, 6.4, and 6.5) save the terrestrial carbon fluxes and also (if not too difficult) the ocean carbon fluxes.
6) Results for the prescribed SST simulations should be reported for all months run, including the initial transient period.
7) During at least one year of simulation 6.2a, the traditional method of estimating radiative forcing at the surface and top of the atmosphere should be applied in which two calls to the radiation code are made each time step, once with $1xCO_2$

and then with 4xCO_2, but with only the heating rates from the 1xCO_2 actually impacting the model. This will isolate the immediate impact of quadrupling CO_2 (before various other “fast” responses occur).

8) Expts. 6.5 to 6.8 are CFMIP experiments which aim to isolate the role of atmospheric processes in the response of clouds and precipitation to prescribed CO_2 radiative forcing and SST perturbations. Expts. 6.5, 6.6 (Tier 1) and 6.8 (Tier 2) are peformed in ‘realistic” conditions while expts. 6.7a,b,c (Tier 1) are performed in ‘simplified’ (aqua-planet) conditions. The ‘control’ run of the experiments run in ‘realistic’ conditions is the AMIP run (expt. 3.3). These short, atmosphere-only experiments may be run by all types of models (ESMs, OAGCMs, very high-resolution models, chemistry-climate models and NWP models).

e. Simulations for climate change detection and attribution studies.

In order to attribute observed climate change to particular causes, it is essential to perform simulations of the historical period (so-called 20th century runs) with only a subset of known forcing. Multi-member ensembles are useful because the forced response can be better determined. Experiments for this purpose are listed in Table 7.

The purpose of these experiments is to determine whether model predicted responses to various forcing is identifiable in the observational record. The larger the ensemble, the better determined will be the forced response (i.e., the signal).

Table 7. Simulations for climate change detection and attribution studies.

	#	Experiment	Notes	# of years
TIER 1	7.1	Natural-only (1850-2005)	Impose conditions as in the control experiment (3.1), but with natural forcing (e.g., volcanoes and solar variability) evolving as in the historical run (expt. 3.2).	156
	7.2	GHG-only (1850-2005)	Impose conditions as in the control experiment (3.1), but with greenhouse gas forcing evolving as in the historical run (expt. 3.2). This can yield an estimate of the contribution of greenhouse gas forcing to recent warming, and when used in combination with the “all forcings” experiment (3.2) and “natural-only forcings experiment (3.1), the response to aerosols can be estimated as a residual.	156
	7.3	Other individual forcing runs	Consider, for example, land use changes only, or anthropogenic aerosols only or anthropogenic sulfate aerosols only, or volcanic aerosols only, etc..	(≥1)x156
TIER 2	7.1-E, 7.2-E, 7.3-E	Individual forcing ensembles	Create multi-member ensembles for expts. 7.1-7.3, initialized from different points in the control run (expt. 3.1). Natural-only is highest priority with GHG-only next.	(≥1)x(≥2)x156